EVALUATING DRIVER ACCEPTANCE OF HEAVY TRUCK VEHICLE-TO-VEHICLE SAFETY APPLICATIONS

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ABSTRACT

This paper describes the results of a study to determine the acceptance of drivers of vehicle-to-vehicle (V2V) safety applications in Class 8 heavy trucks. This study was conducted to provide some of the information and data needed to assess heavy truck V2V safety benefits. Driver Clinics were conducted in two locations in the U.S. to evaluate acceptance of the connected vehicle technology and safety applications by volunteers with Commercial Driver's Licenses (CDL) who were previously unfamiliar with the technology. Two heavy truck tractors with integrated V2V Safety applications were developed and used for this study.

The V2V safety applications tested included a Forward Collision Warning (FCW), Blind Spot/Lane Change Warning (BSW/LCW), Emergency Electronic Brake Lights (EEBL), and an Intersection Movement Assist (IMA). Warnings were presented to drivers in the form of a visual display mounted in the cab and also audio warnings. Driving scenarios were developed to demonstrate each V2V safety application. Drivers were recruited for this study from local trucking fleets, independent owner-operators, and respondents to advertisements both online and in local truck stops. After an initial briefing and practice drive time in the truck, participants completed a series of scenarios and were given in-vehicle questionnaires after each scenario and a final questionnaire at the end. Approximately half of the drivers were selected for in-depth interviews following the drive. In addition, the vehicles were instrumented with a data acquisition system (DAS) that collected engineering and video data from each drive. As V2V safety systems are further refined for all vehicle types, understanding the acceptance by commercial vehicle drivers of this new technology is important so that anticipated safety benefits for heavy trucks can be fully achieved.

INTRODUCTION

Two driver acceptance clinics (DACs) were conducted to determine heavy-truck driver acceptance of collision-warning systems based on vehicle-to-vehicle (V2V) technology. In short, V2V technology involves the transmission of vehicle information between vehicles via Dedicated Short Range Communications (DSRC) at 5.9 GHz radio frequency. Specifically, onboard computers broadcast information such as current vehicle location, size, speed, and path history. Using that same information received from other vehicles, the system can predict impending collisions and provide a warning to the driver.

This paper begins with a brief overview of the DACs and the safety applications that comprise the V2V-based collision-warning system. Following that are the aims and results of the analysis of the results of the DACs, as conducted by the Volpe National Transportation Systems Center.

Overview of Heavy Truck DACs

The DACs are part of a series of tests of V2V technology conducted by the U.S. Department of Transportation known as Safety Pilot [1]. The Safety Pilot consists of two parts, Driver Acceptance Clinics and the Model Deployment. The Model Deployment, which is a large-scale field test being conducted on the streets of Ann Arbor, Michigan, in which volunteer participant drivers use vehicles with fully-integrated V2V systems in their regular day-to-day driving. The DACs were conducted before the Model Deployment began and provided initial data on driver acceptance as well as an opportunity to further refine the V2V technology before the Model Deployment. Both the Driver Acceptance Clinics and Model Deployment generate data that will be used by the National Highway Traffic Safety Administration for potential agency decisions related to V2V technology.

Driver Acceptance Clinics for passenger vehicles were held from August 2011 to January 2012 to test V2V safety applications with volunteer participant drivers in controlled roadway situations. The evaluations explored driver reactions to safety applications using a variety of cars in six locations in the U.S. The driver clinics were designed to identify how drivers respond to the V2V safety applications and assess drivers' response to and benefits from in-vehicle alerts and warnings and not other issues such as security and privacy. Over 600 drivers in total experienced the technology with generally positive responses from drivers [2].

In order to support potential agency decisions on heavy vehicles, the U.S. DOT has contracted with a Connected Commercial Vehicle (CCV) Team led by Battelle that includes Mercedes-Benz Research and Development North America, Daimler Trucks North America, Denso, Meritor WABCO, and the University of Michigan Transportation Research Institute, to develop connected vehicle on-board equipment (OBE) and safety applications on selected Class 8 commercial vehicles and to build vehicles for research and testing activities to provide information and data needed to assess safety benefits and support NHTSA agency decisions. The Heavy Vehicle Driver Acceptance Clinics are some of the many tests and demonstrations of heavy vehicle connected vehicle technology during this project.

The heavy-truck driver clinics were conducted by the Battelle team in 2012 at two separate test tracks: at the Transportation Research Center in East Liberty, Ohio, from July 10-26, and at the former Alameda Naval Air Station in Alameda, California, from August 22-23. In both clinics, volunteers were asked to drive V2V-equipped vehicles through scripted interactions with other vehicles that were driven by professional drivers. These interactions were designed to demonstrate different types of collision warnings. For each warning, a test conductor sitting in the passenger seat described to the volunteer how to drive and what would happen before the demonstration was conducted.

A total of 112 participants from local trucking fleets, independent owner-operators, and respondents to advertisements both online and in local truck stops volunteered, of which 64 were in the Ohio clinic and 48 in the California clinic. Among other criteria, volunteers had to be at least 21 years of age, possess a valid Class-A Commercial Driver License (CDL-A), currently drive a tractor trailer, and not have had more than two moving violations in the last three years or to have caused an injury or crash in the last three years. Subjects were not equally balanced by gender (most were male) or age, but were meant to be representative of the demographic of professional truck drivers currently on the road.

The two vehicles demonstrating the V2V technology are shown in Figure 1. Both were Freightliner Cascadia Class 8 heavy trucks. The white truck had a high-roof sleeper body and the red truck was a mid-roof sleeper. Both towed empty 53-foot van semitrailers and were purchased specifically for the DACs.

Figure 1. **The demonstration trucks used in the DACs.**

V2V-Based Safety Applications

Trucks were equipped with four different safety applications, each designed to warn against a different type of collision scenario. In all cases, visual warnings were displayed on an iPad mounted on the center of the dashboard (Figure 2). Warnings to the driver consisted of both visual icons displayed on the screen and auditory beeps emitted from speakers mounted at roof height on both sides of the interior of the truck cab.

The four safety applications and their accompanying visual icons are shown below in the order in which they were demonstrated to drivers. The auditory warnings did not differ between safety applications, but were different for "cautionary" and "imminent" warnings.

***Figure 2*. Placement of the display in the truck cab.**

<u>Intersection Movement Assist (IMA) -</u> Warns drivers of a vehicle approaching from the side while entering an intersection (Figure 3). In this case, the subject was instructed to release the brakes and roll into an intersection as a passenger vehicle approached from the left at a constant speed. In all scenarios, the participant drove the tractor-trailer (illustrated in blue in the figure). A single-unit truck (illustrated in green) was parked at the corner in order to obstruct the participant's view of the approaching passenger car (illustrated in red), which comprised the threat. On the right side of Figure 3 are the visual icons displayed to the driver: on top is the cautionary warning and below is the imminent warning. . The system first issued a cautionary alert followed by an "imminent" alert.

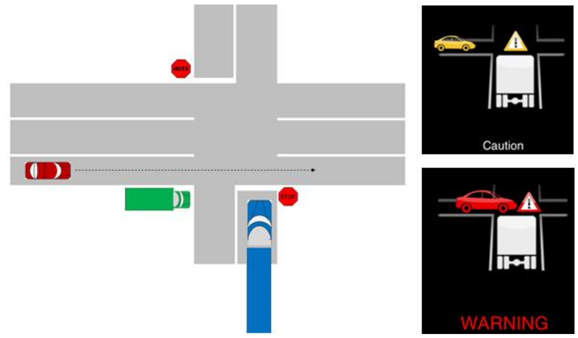

***Figure 3.* Intersection Movement Assist scenario and associated cautionary and imminent warnings displayed to driver.**

<u>Forward Collision Warning (FCW)</u> Warns the driver if they are approaching a stopped or slower lead vehicle (Figure 4). In this scenario, the system issued a cautionary and then imminent alert as the participant's vehicle approached a stopped passenger vehicle. The participant drove the blue truck toward a stopped passenger car, shown in red. Below Figure 4 are the visual icons displayed to the driver: on the left is the caution and on the right is the imminent warning.

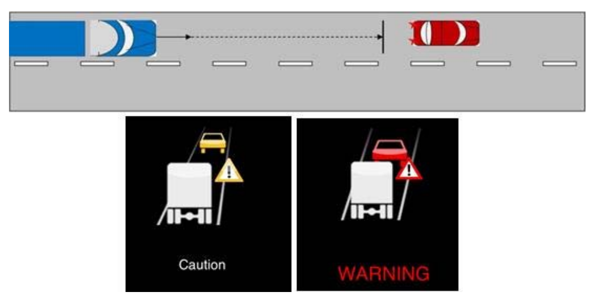

***Figure 4.* Forward Collision Warning scenario and associated cautionary and imminent warnings displayed to driver.**

<u>Emergency Electronic Brake Lights (EEBL)</u> - Warns the driver if there is hard braking one or more vehicles ahead in the traffic queue (Figure 5). In this scenario, the participant drove behind two vehicles, including a single-unit truck directly in front of the participant's truck that blocked the participant's view of a passenger car farther ahead. The driver of the passenger car then abruptly applied its brakes. If the vehicles were in an adjacent lane, the system would issue a cautionary warning. If they were in the same lane, an imminent warning would be issued. This alert was not dependent upon the intermediate vehicle braking (single-unit truck in this scenario), but instead was intended to provide information on traffic farther ahead. For this safety application only, there was no audio for the cautionary warning (but there was for the imminent warning). In this scenario the participant drove the blue truck. The red passenger car braked but was obscured from the view of the blue truck by the green truck, which did not brake. Below are the visual icons displayed to the driver: on the left is the caution and on the right is the imminent warning.

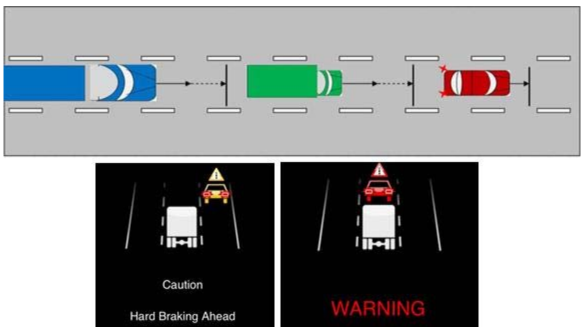

***Figure 5*. Emergency Electronic Brake Lights scenario and associated cautionary and imminent warnings displayed to driver.**

<u>Blind Spot/Lane Change Warning (BSW/LCW) -</u> Indicates to the driver that there is a vehicle in their blind spot (Figure 6). In this scenario, the participant was driving down a road at a constant speed of 35 mph. When a passenger car entered the participant's blind spot in the adjacent lane, the system issued a cautionary alert (the BSW). When the participant activated their turning indicator in the direction of the lane in which the passenger car was driving, the system issued an imminent alert (the LCW).

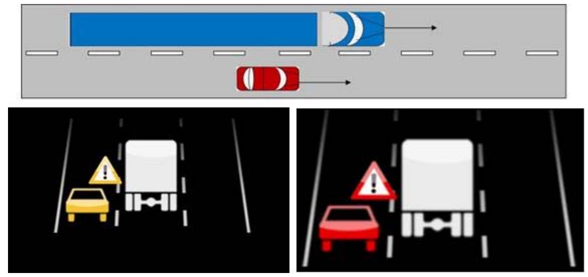

***Figure 6*. Blind Spot Warning scenario and associated cautionary and imminent warnings displayed to driver.**

After the IMA demonstration and before the FCW demonstration, participants were asked to accelerate and to practice hard braking.

In total, participants spent approximately 90 minutes in the vehicle, a third of which was spent driving in the scenarios with the remaining time being used to explain each scenario and complete questionnaires. After checking in, participants were first given an overview of the study, an orientation of the vehicle and course, and then sat behind the wheel and took part in the demonstrations. Their participation ended when they were debriefed and paid.

Data Collection

Participants filled out three different surveys, each at a different time: "pre-drive" surveys before the demonstrations; "in-vehicle" surveys for each safety application immediately after experiencing it; and "post-drive" surveys after the demonstrations were complete and participants had left the vehicle. Additionally, half of drivers participated in a verbal post-demonstration interview in which they were asked to further explain their impressions and concerns regarding the V2V technology.

The surveys themselves consisted of both open-ended questions (*e.g.,* "Do you have any concerns, ideas for improvement, or other comments for the blind spot warning?") and questions to be answered on a Likert scale. The Likert-scale items consisted either of questions or statements that participants rated their agreement with (Figure 7).

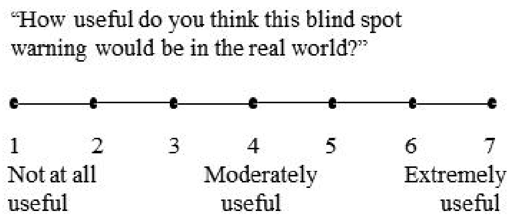

***Figure 7*. Example of Likert scale used in questions.**

A more detailed description of the experimental design can be found in the DAC test report prepared by the Battelle CCV Team [3].

ANALYSIS METHODOLOGY

Objectives

The aim of this analysis is to assess driver acceptance in terms of both the compatibility between participants' expectations of the technology and its performance, as well as in terms of the degree to which participants express interest in having the technology in their vehicles. "Driver acceptance" is a complex combination of several different factors that influence whether drivers will want the technology and how well it will work for them. These factors may vary independently of one another and it is therefore useful to analyze them separately in order to gain a more nuanced understanding of why and how drivers do or do not accept a technology. In this study, acceptance is defined in terms of five criteria that comprise the objectives of the analysis:

1. **Usability:** Do participants think that the V2V safety applications are easy to use?
2. **Perceived Safety Benefits:** Do participants think that V2V technology will contribute to their driving safety?
3. **Understandability:** Are the V2V safety applications easy to understand and learn to use?
4. **Desirability:** Do participants want to have and use V2V safety applications in their truck?
5. **Security and Privacy:** How do participants feel about the security and privacy issues raised by V2V technologies?

Of particular interest is the risk of unintended consequences, including overreliance or distraction caused by the V2V technology, which falls under the second objective above.

METHODS

Non-parametric tests, such as Mann-Whitney and Kruskal-Wallis tests, were used since data collected on a Likert scale cannot be assumed to be on an interval scale (the magnitude of the difference between a response of, for example, a four and a five, cannot be assumed to be the same as the magnitude of the difference between a five and a six). Medians were used instead of means for the same reason.

One of the downsides of having participants answer survey questions on a scale of one to seven is its inherent subjectivity: one participant's five might be equivalent to another's seven. In order to remove some of that subjectivity, for the analysis scores were converted to one of three bins: "negative," "neutral," or "positive" (the actual names of these bins varied from question to question depending on the wording of the question at hand). The bins were divided according to a system of 12-345-67, i.e., with scores of one and two as "negative," three through five as "neutral," and six and seven as "positive." This 12-345-67 breakdown was used instead of a 123-4-567 breakdown because it is more conservative and because so many of the responses were strongly positive and the chance of finding meaningful changes in the results is higher if the upper responses are separated from the middling ones—otherwise the results would likely be almost exclusively "positive."

Open-ended responses were summarized in terms of the overarching or dominant concerns or issues raised. They were also used to clarify unusual responses (such as outliers) and to illustrate concerns or trends seen in the numerical Likert-scale responses. Finally, all responses were checked for anything related to security and privacy to determine whether participants raised concerns about those issues. An analysis of the post-drive verbal interview sessions is not presented here.

RESULTS

What follows are the results of the analyses conducted by the Volpe Center and outlined in the preceding section. The total number of participants (*n*) answering each question varies in some cases because participants occasionally left questions blank.

Effect of Driver Clinic

Before pooling the data from the two clinics, one in Ohio and one in California, the results from each were compared to rule out an effect on driver acceptance of some variable, such as scenery, track layout, or weather conditions that varied between them (the staff that administered the tests were the same for both clinics). For each question answered on a Likert scale (a total of 26 questions), the percent of scores that were positive (a score of six or seven) were compared between clinics. No significant difference was seen between clinics: the pattern of the scores was similar, as indicated by a significant positive correlation between both clinics (*Pearson's r* = 0.9, $n = 26$, $p < 0.001$, two-tailed); and the magnitude of the scores was similar, as indicated by a small mean difference (1.4 percentage points, 95-percent confidence interval between 1.0 and 3.8 percentage points) and no significant difference between clinics (*paired* t*-test*, $t = 1.2$, df = 25, $p = 0.24$, two-tailed). The responses from the two clinics were therefore pooled for all subsequent analyses.

Responses Grouped by Objective

The following stacked bar charts show the results from all three surveys (pre-drive, in-vehicle, and post-drive), grouped by analysis objective. The charts illustrate the percentage of responses that fell into each of the three score bins (split according to 12-345-67). The number of respondents in each bin is written over the bars.

Usability. All safety applications were rated on the in-vehicle survey as effective by the majority of participants (Figure 8). There may have been an order effect, though, as the order in which participants experienced the safety applications was the same for all participants and corresponds with the relative effectiveness rating below, with the last-experienced safety application (BSW/LCW) being rated highest and the first-experienced safety application (IMA) being rated lowest.

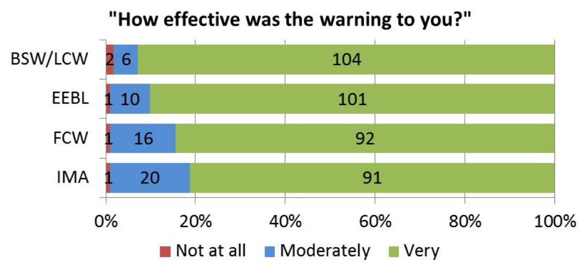

***Figure 8*. The effectiveness of the different safety applications.**

One factor that plays a role in effectiveness is whether alerts are auditory only, visual only, or both. For each safety application, participants were asked which type of alert was the most useful. In the demonstration, all participants experienced simultaneous auditory and visual warnings (though they may not have always noticed both). The results showed most thought that having both a visual and an auditory component to the alerts was most useful (Figure 9), and considered the visual warnings to be "clear and obvious" (in-vehicle survey; Figure 10—unlike the other questions on a seven-point scale, this question allowed an answer of zero for those who did not notice a visual warning at all). Of those who preferred to receive only an auditory warning, most expressed a desire not to take one's eyes off the road during an emergency situation in order to look at the display. This concern was raised in the open-ended answers multiple times, with drivers stating a preference for a heads-up display, one on the windshield, or simply stating their unease with looking away from the road.

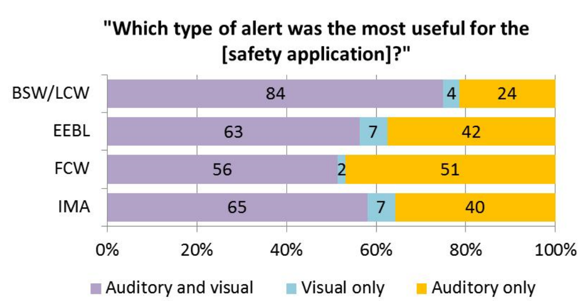

***Figure 9.* Usefulness of alerts presented only as auditory, visual, or as both, for each safety application.**

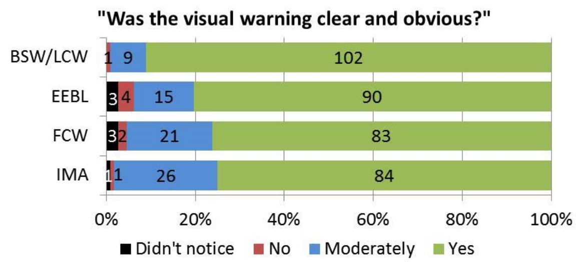

***Figure 10.* Clarity of visual warnings for each safety application.**

<u>Perceived safety benefits</u>. Participants gave very high approval rates to the perceived safety benefits conferred by each safety application overall during the in-vehicle surveys (Figure 11). Of those applications, the BSW/LCW received higher ratings of usefulness than the EEBL, which received higher ratings than the FCW. The IMA received the lowest number of high ratings (though it also received no "not useful" ratings).

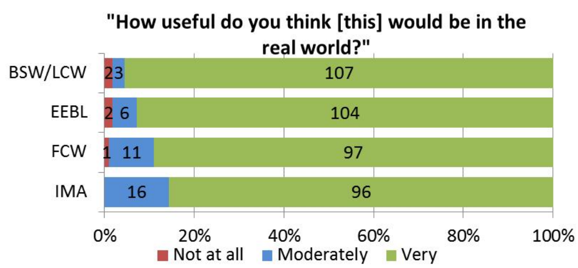

***Figure 11.* Rated "real world" usefulness for each safety application.**

Again, the above relative preferences between safety applications may be affected by the order in which the applications were experienced, since the order is the same as the inverse of the order of preference, with the application rated most useful being experienced last and the least useful being experienced first. That this may be an order effect is addressed by responses to a question on the post-drive survey: "rank in order of usefulness of each application, starting with 1 being the MOST useful to 4 being the LEAST useful." Here the mean ranks were different: BSW/LCW (2.1), EEBL (2.2), IMA (2.7), and FCW (3.0).

The following two questions from the post-drive survey concerned participants' opinion of the potential for driver distraction as caused by the safety applications. These questions reveal an overall perception that, although 75 percent of participants estimate the degree of distraction caused by the applications to be comparable to operating the truck's stereo system (the same percentage was found in the report on the light-vehicle DACs [4]) (Figure 12), nonetheless 81 percent believed there was some likelihood of drivers becoming dependent upon the warning systems to alert them to danger (Figure 13).

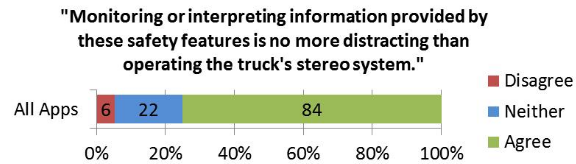

***Figure 12.* Distraction potential.**

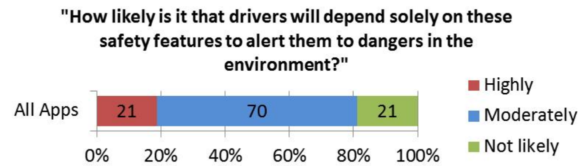

***Figure 13.* Likelihood of overreliance on safety applications.**

Several drivers expressed further concern for unintended consequences in question 21 of the post-drive survey: "Each driver must learn not to rely on these safety devices. Still no substitute for driver looking and staying alert;"

"The only con of all these things that I can see in the future is that some of the future drivers may begin to rely on this technology too much and pay less attention to the actual road;"

"Warning not to depend on system. Must be used with SAFE driving practices. There are (maybe) legal implications for ignoring warning system. Driver should be made aware;" and

"I think this is helpful and useful. My only reservation is that I believe these systems would hamper drivers in developing instincts. I am a million-mile safe driver and I feel the instincts I have built over the years have been good to me. But if I had the choice in a vehicle with or without this system, I would use the warning system."

Another survey question pertains to the issue of overreliance indirectly. Participants were told, "It is possible that the Vehicle-to-Vehicle Communication safety application may become temporarily unavailable, and not warn you when it otherwise would. With that in mind, please answer the following." Participants were then asked whether or not they would want to receive notification of system unavailability. The overwhelming majority answered affirmatively (Figure 184). This question pertains to overreliance since desiring to know when the system is online implies that drivers may act differently with the system on or off.

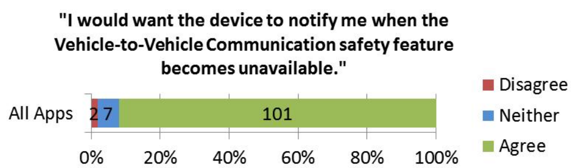

***Figure 14.* Desire for being notified when the system becomes unavailable.**

<u>Understandability</u>. When asked during the in-vehicle survey to rate agreement with the statement that a given safety application was easy to understand, the large majority of participants rated their understanding as high for each application (Figure 15).

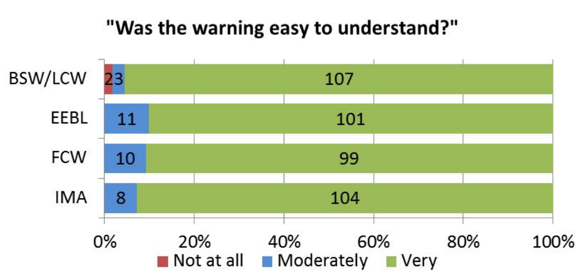

***Figure 15.* Rated understanding of the safety applications.**

In the post-drive survey, a large number of participants reported feeling that there would be some confusion in interpreting which warnings were provided by which safety applications (Figure 16).

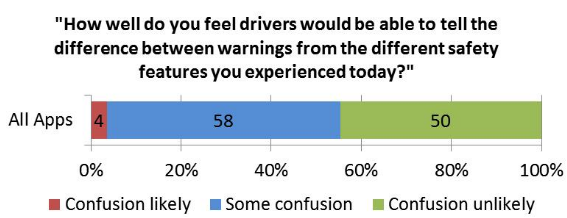

***Figure 16.* Rated potential for confusing the safety applications.**

Participants were asked after completion of the demonstrations how well they understand the technology and how it works. From the wording of the question, it is unclear whether positive responses indicate an understanding for the basic logic of the system, e.g., "the system beeps when I'm in danger of hitting someone," or how the technology works on a more fundamental level, with vehicle information being broadcast and received via DSRC, etc. Most participants stated "full comprehension" of the technology, with only one driver saying they don't understand (Figure 17).

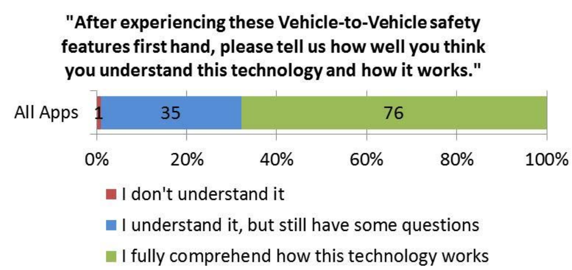

***Figure 17.* Reported understanding of "how [V2V] technology works." The question was multiple choice and participants were asked to check only one of the three options.**

<u>Desirability</u>. The following questions from the post-drive survey indicate that the vast majority of participants would like to have V2V technology (Figure 18).

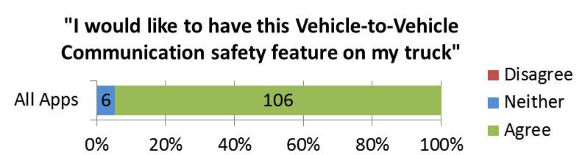

***Figure 18.* Desirability of the combined package of all four safety applications.**

When broken down by individual safety application in the in-vehicle surveys, the IMA was again the least strongly rated—but as before, even it was still rated overwhelmingly positive, with over 87 percent of respondents giving it a six or seven (Figure 19).

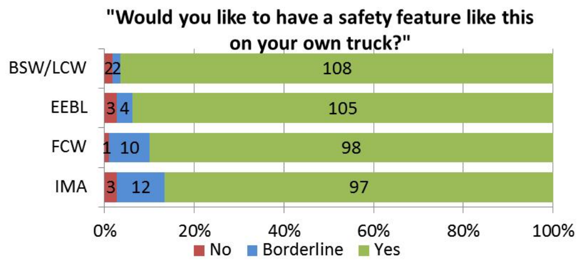

Figure 19. **Desirability of the individual safety applications.**

When compared with other options for vehicle systems, desire for V2V technology was highest: in order from most to least desirable, participants ranked the options first V2V, then FCW (via Eaton Vorad or Meritor OnGuard), then Adaptive Cruise Control, then stability control systems, then GPS, and finally tire-pressure monitoring systems. Table 1 shows the mean rankings for different vehicle systems in response to the question, "Please rank the following options in terms of overall desirability, with 1 being the MOST preferred and 6 being the LEAST. Use numbers 1-6 only once." Row order is the same as it was in the survey.

Table 1.
Mean rankings for different vehicle systems.

Available Option	Mean Rank
Adaptive Cruise Control (slows down when somebody is in front of you)	3.8
Forward Collision Warning System (Eaton Vorad or Meritor OnGuard)	2.7
GPS Navigation System	4.2
Roll Stability Control or Electric Stability Control	4.0
Tire Pressure Monitoring System	4.5
Vehicle-to-Vehicle Warnings (All of the safety applications you experienced today)	1.8

Security and privacy. There were no questions asking participants directly about security and privacy concerns (it could be argued that to ask about such concerns directly is to ask a leading question, thus creating the concerns in drivers' minds, rather than checking to see if they initially had them). Consequently, the responses to the open-ended questions were checked for anything related to security or privacy that drivers raised on their own. Of most relevance was question 21 of the post-vehicle survey, which asked, "any final thoughts or comments on your overall experience today that you would like to provide?" Only one out of the 112 participants raised an issue that pertained to either security or privacy, namely, "can someone rig something to send false info to mess with a driver?"

Environmental Conditions

For each safety application, participants were asked in the post-drive survey, "under what environments and conditions do you feel the safety application would provide the most benefit? (Circle all that apply)." The possible answers included: nighttime driving, daytime driving, slippery roads, poor visibility, unfamiliar roadways, obscured views, and "other." Overall, participants picked all options with high frequency for each safety application. For the IMA warning, poor visibility and obstructed views were the most widely chosen. For FCW, all options except daytime driving were commonly picked. The responses for EEBL and BSW/LCW were similar. Representative written-in responses to the "other" option are provided below each chart. "Heavy traffic," "rush hour," and "distracted/tired" drivers were common answers for all safety applications. Situations obstructing views were listed for the IMA, and factors causing vehicles to suddenly stop were listed for the FCW and EEBL alerts. Several drivers cited "motorcycles passing on the right" as a use for the BSW/LCW safety application.

For the IMA, participants wrote the following under the option for "other": "city driving;" "when pulling from driveways or blind intersection;" "tired drivers / distracted drivers;" "could save a tired driver from making a mistake he wouldn't normally make;" "heavy traffic;" "trees and signs block trucks a lot;" "over the hill;" "a stoplight on a four-lane highway. The light changes for you, but the driver in the outside lane doesn't stop. This warning would be very helpful."

For the FCW, participants wrote the following under the option for "other": "stop-and-go traffic," "heavy traffic conditions," "during rush-hour traffic in large cities;" "two-lane country roads;" "tired drivers / distracted drivers," "when thinking or daydreaming;" "cars stopped due to an accident or break down."

For the EEBL, participants wrote the following under the option for "other": "commuter traffic, heavy;" "stop-and-go traffic, like rush hour traffic when vehicles are close together;" "freeway or highway driving;" "stalled vehicles in lane;" "tired drivers / distracted drivers;" "heavy traffic / downhill;" "animals running across the road causing a car to slam on the brakes;" "a warning for stopped traffic that might be on the other side of a hill such as mountain back-up going down the other side."

Lastly, for the BSW/LCW, participants wrote the following under the option for "other": "making right turns;" "motorcycle riders that pass on right;" "rush-hour traffic;" "when driving in lots;" "tired drivers / distracted drivers;" "when driver's been on the road for a while;" "leaving or entering toll booth."

Effect of Age

Of the 112 volunteers who took part in the clinics, the age ranged from 28 to 66 years old. The mean age was 47.2 years old, with a standard deviation of 9.3 years.

Correlation analyses. Spearman correlation tests were conducted to test for relationships between responses to Likert-scale survey questions and years of age. There were a couple statistically significant correlations (p-values < 0.05), which is no surprise given the large sample sizes, which ranged from 108 to 111. However, the important measure in such correlations is not the degree of significance but the magnitude of the correlations, and in that case nothing was found: all of the correlation coefficients (r_s) were between 0.2 and -0.1 and were therefore very weak or non-existent. In other words, there did not appear to be any non-weak linear relationships between survey responses and age. This was true both for the safety applications individually, as well as for the combined system.

Analysis comparing "age bins." Age was also analyzed by dividing the subjects into subgroups ("bins") by age and comparing the ratings given by those groups using non-parametric between-subject tests. The analysis focused on Likert-scale questions related to driver acceptance. Three groups were used: 28-39, 40-49, and 50-66. Kruskal-Wallis omnibus tests were used to compare all three age bins between subjects. No significant differences were found between age groups (in all cases $p > 0.05$).

Effect of Previous Driving Route Experience

When asked to report the number of years with a CDL-A license, the mean response was 18.6 years, with a standard deviation of 11.7 years. The least amount of time was five months and the longest 41 years. With regard to the number of years of experience driving a tractor trailer, the mean response was 17.7 years, with a standard deviation of 11.8 years. The least amount of time was again five months and the longest 41 years.

To determine whether there is a difference in the acceptance of V2V technology between route types, subjects were divided into three groups: those who have driven only local "pick-up & delivery" (P&D), those who have driven only line haul and those who have driven both (those who have driven neither should, and was, and empty group). This division was based on the survey question in which drivers were asked, "What types of routes do you have experience driving?" Participants were provided with five choices of answers:

a. Local
b. Over the road
c. City driving
d. Truckload
e. Less than truckload

In this case, answers to (a) and (c) were considered P&D, and (b) was considered line haul. The vast majority of drivers have experience with both types of routes and no drivers had experience with neither. See Figure 20.

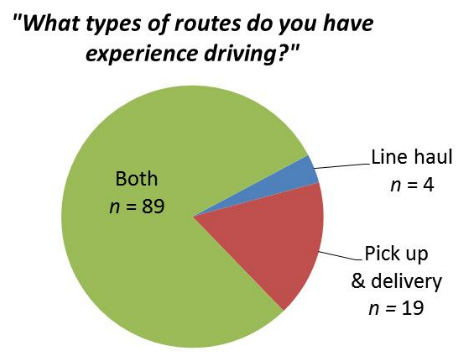

Figure 20. **Reported route experience in terms of line haul, pick up & delivery, or both.**

Effect of Previous Experience with Safety Applications

Although collision-warning systems based on V2V communication are a new technology, collision-warning systems based on other technologies, such as onboard radar or cameras, are already in use. To determine whether prior experience with other types of warning systems may have affected subjects' acceptance of V2V-based technology, the pre-drive survey included two questions regarding other types of systems. The first asked drivers, "Which of the following devices are installed or available to you in your primary truck?" (question 9). The second asked, "which devices would you like to have installed or available in your truck?" (question 10). For both questions a range of devices were then listed, next to which participants could check one of three columns: for question 9, "installed" / "don't know" / "not installed"; and for question 10, "desirable" / "don't know" / "not desirable." Of the 21 devices listed, six were identified as including capabilities similar to the V2V safety applications used in the DACs, namely audio or visual warnings for impending collisions. Those six included Cadec, Eaton Vorad, Forward Collision Warning (FCW), Lane Departure Warning (LDW), OnGuard, and Wingman.

Table 2 shows the responses to device possession and desire, grouped by device. There was a large degree of uncertainty in terms of what devices drivers had in their vehicles, although most drivers had none of them. The type of device known to be in the vehicle most frequently was Cadec. The devices with the least uncertainty regarding possession were the LDW and FCW warnings. These were also the two most desired devices—the rest had a large degree of uncertainty regarding desirability. They are also the two devices with descriptive rather than brand names. For the most part, the devices all received very few "not desirable" ratings.

Table 2.
Number of drivers that reported having a given collision-warning device on their vehicle and the number of drivers that reported desiring a given device on their vehicle.

Device	Installed in primary truck?		
	Not installed	Don't know	Installed
Cadec	37	39	9
Eaton Vorad	48	30	4
FCW	71	9	8
LDW	72	9	3
OnGuard	64	14	5
Wingman	62	17	2

Device	Like to have?		
	Not desirable	Don't know	Desirable
Cadec	8	59	12
Eaton Vorad	11	60	13
FCW	3	7	89
LDW	4	18	76
OnGuard	8	51	31
Wingman	6	64	18

The data in Table 2 are broken down by driver rather than by device type as in Table 3. In total, 25 drivers gave no answer for any of these six devices for either the "do you have it installed?" or the "do you want it installed?" questions, and were dropped from the table. Only 22 percent of drivers (19 drivers) had at least one warning device already, and of them 89 percent wanted at least one of them. Of the 78 percent of drivers that had none of the devices in their primary trucks, 90 percent wanted to have at least one of them.

Table 3.
Number of drivers who have and want at least one of the six devices (listed in Table 2) that provide some form of collision warning

		Want installed?		
		At least one	None	Total
Have installed?	At least one	17	2	19
	None	61	7	68
	Total	78	9	87

Outlier Analysis

Overall, the participants had a very clear positive response to V2V technology. As reported above, when asked in the post-drive survey to report their agreement with the statement, "I would like to have this Vehicle-to-Vehicle Communication safety application on my truck" (Figure 18), responses were strongly positive. As in the light-vehicle DAC [4], the median response was the maximum response, a seven. In the analysis of the light-vehicle DACs, this question was used to identify negative outliers, which were defined as those who rated agreement three or less (out of 406 drivers, nine qualified as negative). However, in the heavy truck DACs no drivers gave ratings less than five, meaning *all* responses were at least somewhat positive. Consequently, outliers were identified based on their scores rating the safety applications individually: subjects were deemed outliers when for at least one safety application they gave a response of less than four to the question, "would you like to have a safety application like this on your own truck?" To explore these outliers, Table 4 shows how those individuals responded to other questions. Note: the column labeled "ALL" is neither the mean nor the sums of the other columns, but rather the answer to a separate question referring to the suite of safety applications combined. Scores below four are shaded red. Dashes indicate that no answer was recorded for that run.

Table 4.
Outlier analysis listing responses to several questions by participants who rated at least one individual safety application as undesirable by giving a less-than-neutral score (less than four).

		Would you like to have it?					How useful would it be?			
ID	Age	IMA	FCW	EEBL	BSW/ LCW	ALL	IMA	FCW	EEBL	BSW/ LCW
19	58	3	4	1	6	4	4	5	2	5
20	60	7	7	7	1	7	7	7	7	1
36	35	7	-	1	7	7	7	-	2	7
40	29	6	5	2	7	5	6	6	4	7
42	47	6	2	7	7	7	6	7	7	7
50	50	3	7	6	7	7	4	6	7	7
54	30	3	7	5	7	5	4	2	5	7
55	48	1	4	7	7	6	4	5	7	7
67	44	2	7	7	7	6	4	7	7	7
85	56	7	7	7	1	7	7	7	7	1
89	35	1	7	6	7	6	4	7	4	7

Overall, it appears that, for a given safety application, participants rated usefulness slightly higher than desirability, a finding consistent with the light-vehicle DAC outlier analysis (the only internally inconsistent answer in this regard is Participant 54, who strongly desired the FCW alert in spite of giving it a very low rating of usefulness). Likewise, even though participants may have rated a given safety application undesirable, they tended to rate other safety applications highly, indicating that their aversion is specific to the warning rather than to the idea of warning systems or V2V technology in general.

These outlier participants made comments in the open-ended questions that can explain why they gave low ratings for some systems. Representative comments include: "bigger graphics on screen" (Participant 20); "more audio than visual [to] keep your eyes on the road" (Participant 42); "it's better to keep a driver's eyes in the direction of the danger rather than pulling his vision and attention to the dashboard" (Participant 50); "most would be useful but must be able to adjust. If these are on all the time, driver will not pay attention" (Participant 55);

"the alerts shouldn't sound the same, try to add voices on lane change blind spot" (Participant 89). With regard to the IMA: "my experience was beneficial because I don't believe I had actually moved prior to the warning going off. So the system was extremely effective in that scenario. I like how I just had to let off the brake" (Participant 36); "as a local T/T driver (city), this application would not be useful. Due to high traffic conditions, alerts would be too common" (Participant 55). With regard to the BSW/LCW: the most beneficial aspect was "the visual display because it forced me to look in the direction of my mirror" (Participant 50); and "blind spot alert very useful but in city use this would be on all the time" (Participant 55).

CONCLUSIONS

Overall, driver acceptance of the V2V system in heavy trucks was very high, with the vast majority of drivers giving the maximum rating to most safety applications. The following are the key findings (the five objectives are in bold):

- There was no detectable effect of clinic location, with both those who experienced the Ohio clinics and those who experienced the California clinics giving similar responses.
- **Usability** was rated very high, with at least 81 percent giving strongly positive ratings. However, there appeared to be an order effect, since acceptance of each safety application increased with the order in which it was demonstrated.
- The **perceived safety benefits** were also rated high, with at least 86 percent giving strongly positive scores, although the relative preferences among the different safety applications again appeared to vary with the same order effect. The presence of an order effect was supported by the fact that, when asked afterwards to think back on their ranking of the usefulness of each application, they gave a different order, ranking the IMA above the FCW safety application.
- At least 90 percent of participants gave the highest rating for **understandability**, although 55 percent said there was chance for at least some confusion in differentiating the various safety applications.
- **Desirability** was high, with 95 percent of participants wanting a V2V system on their truck (when safety applications were rated individually, the lowest-rated safety application, the IMA, was still desired by 87 percent of participants, with an additional 11 percent saying they were borderline). Compared to several other available options, including adaptive cruise control and GPS, participants rated V2V the highest.
- Only one participant out of 112 raised the issue of **security and privacy**.
- Between 50 and 75 percent of subjects wanted alerts to have both a visual and an auditory component. Although at least 75 percent thought the visual displays were "clear and obvious," some expressed concern that they draw one's eyes inside the cabin exactly when attention is most strongly needed outside of it. Others voiced concern that audio alerts could be drowned out by the radio.
- Although 75 percent of participants rated the distraction potential of the V2V system on par with their radio system, 81 percent said there was at least some risk that drivers will depend "solely" on the safety applications to alert them to dangers on the road. Relatedly, the fact that 92 percent of drivers would want to be notified when the system becomes unavailable raises the concern that drivers might behave differently with the system on.
- No age effects were observed. This is of little surprise given the relatively narrow age range of participants, which included few very young or very old drivers.

There were very few outliers at the negative end of the spectrum, with not a single driver expressing a negative (less than four) rating of agreement with the statement, "I would like to have this Vehicle-to-Vehicle Communication safety application on my truck," when referring to the combined suite of safety applications. Outliers therefore had to be identified by negative ratings of individual safety applications, of which there were very few. As was the case with the light-vehicle DACs, outliers rated usefulness slightly higher than desirability. That participants who rated a given safety application low tended to rate the other safety applications high suggests that their aversions are specific to the warning and not to the idea of V2V-based warning systems in general.

Regarding an understanding of the underlying technology, although 68 percent said they "fully comprehend how this technology works," it is unclear what level of understanding participants thought the question referred to—whether it meant just an understanding that alerts would be provided when another vehicle got too close, or whether it referred to principles of the underlying technology. This is important because a good understanding of the underlying principles, especially the fact that V2V technology will be constantly broadcasting your vehicle information to others and receiving information that could be falsified, are both central to whether or not one will have concerns with regard to security and privacy. Given the reaction truck drivers have had to devices that monitor their activity, this is likely to be an important factor in fleet acceptance, even if was not raised here.

The experimental design did not control for the order in which participants experienced the different safety applications, as this appears to have affected their relative impressions of the individual systems. Of particular concern is the fact that the IMA demonstration, which entailed being asked to release the brakes and roll into the path of an oncoming vehicle, was conducted before drivers had the opportunity to familiarize themselves with the handling of the vehicle—especially its brakes—with a test drive. The slightly lower scores for the IMA relative to other alert types might therefore be partly due to a lack of comfort driving an unfamiliar vehicle.

Furthermore, many of the drivers expressed admiration for the brand-new trucks used in the DACs, mentioning that they themselves generally operated older vehicles with older technology and less responsive brakes. It is therefore possible that some of the enthusiasm for the warning technology for all of the safety applications may have been affected by enthusiasm for the truck in which it was being demonstrated.

There is also the concern that drivers strongly averse to new technology of this sort are probably less likely to volunteer for studies such as these in the first place.

Finally, since the DACs were designed to demonstrate the value of the safety applications under ideal circumstances without any of the variations, false alerts, and nuisance alerts that come into play in the real world, it is expected that acceptance would be high. Additional information on driver acceptance in the real world will come from the heavy trucks involved in the Model Deployment.

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